



Shutdown Plant Problems

Westinghouse Technology Advanced Manual
Section 4.9

Learning Objectives

1. State the purposes of the Residual Heat Removal (RHR) System.
2. Describe the alignment and operation of the RHR system during its shutdown cooling mode of operation.
3. Describe design features of the RHR system which could reduce its reliability when it is being used for decay heat removal.

Learning Objectives

4. Describe the consequences of losing decay heat removal capability when the reactor is in cold shutdown.



RHR System Purposes

1. Removes decay heat from the core and reduces the temperature of the RCS during the second phase of plant cooldown.
2. Serves as the low pressure injection portion of the Emergency Core Cooling System (ECCS), following a loss of coolant accident.
3. Transfers refueling water between the refueling water storage tank and the refueling cavity before and after refueling.

RHR Shutdown Cooling

- The RHR system is used to remove the decay heat from the core and reduce the temperature of the reactor coolant to the cold shutdown temperature (<200F) after plant shutdown.
- The cooldown performed by the RHR (from 350F to <200F), is referred to as the second phase of plant cooldown.
- The first phase of cooldown is performed using the AFW System in conjunction with Steam Dumps or SG PORVs.

Block Diagram of RHR System

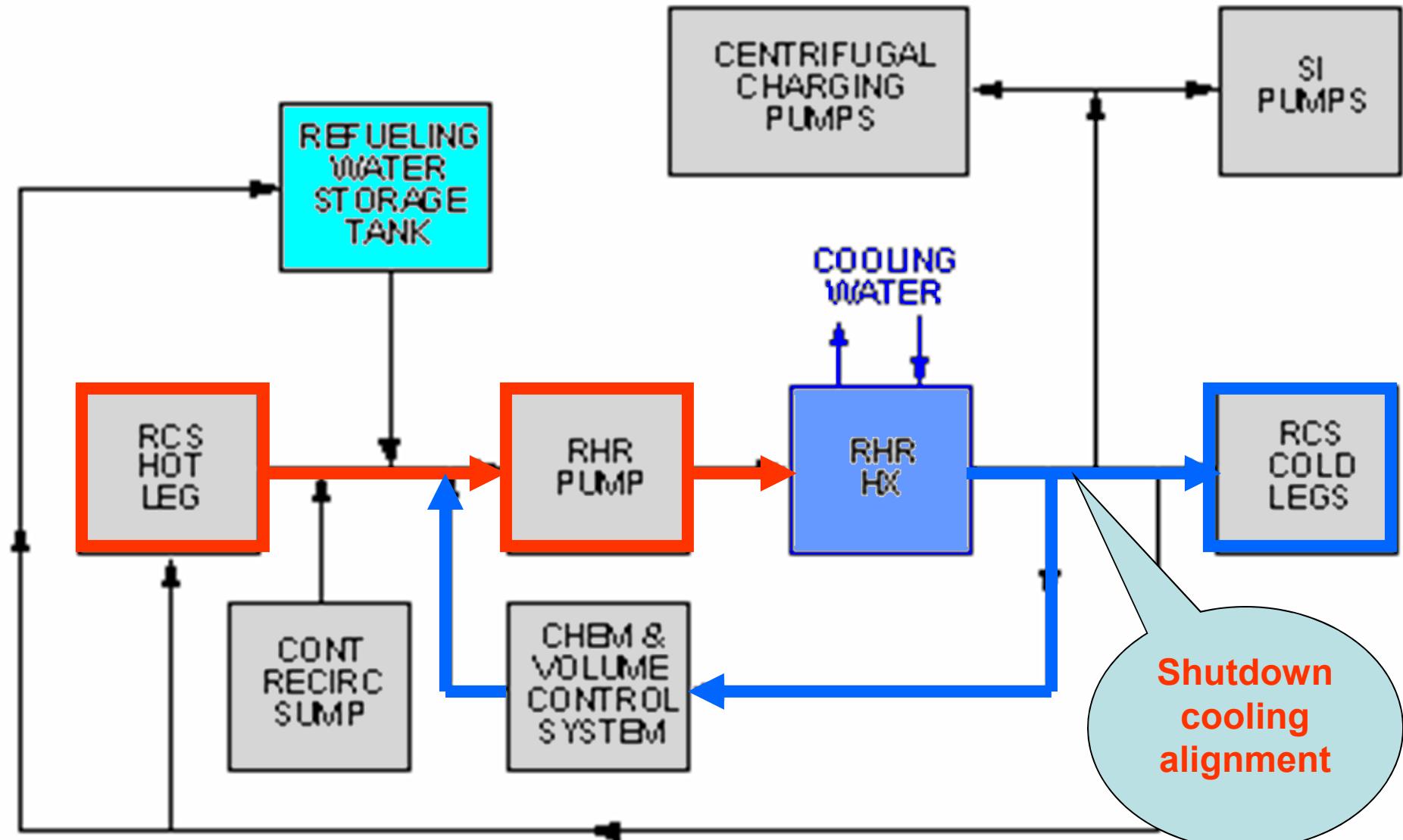
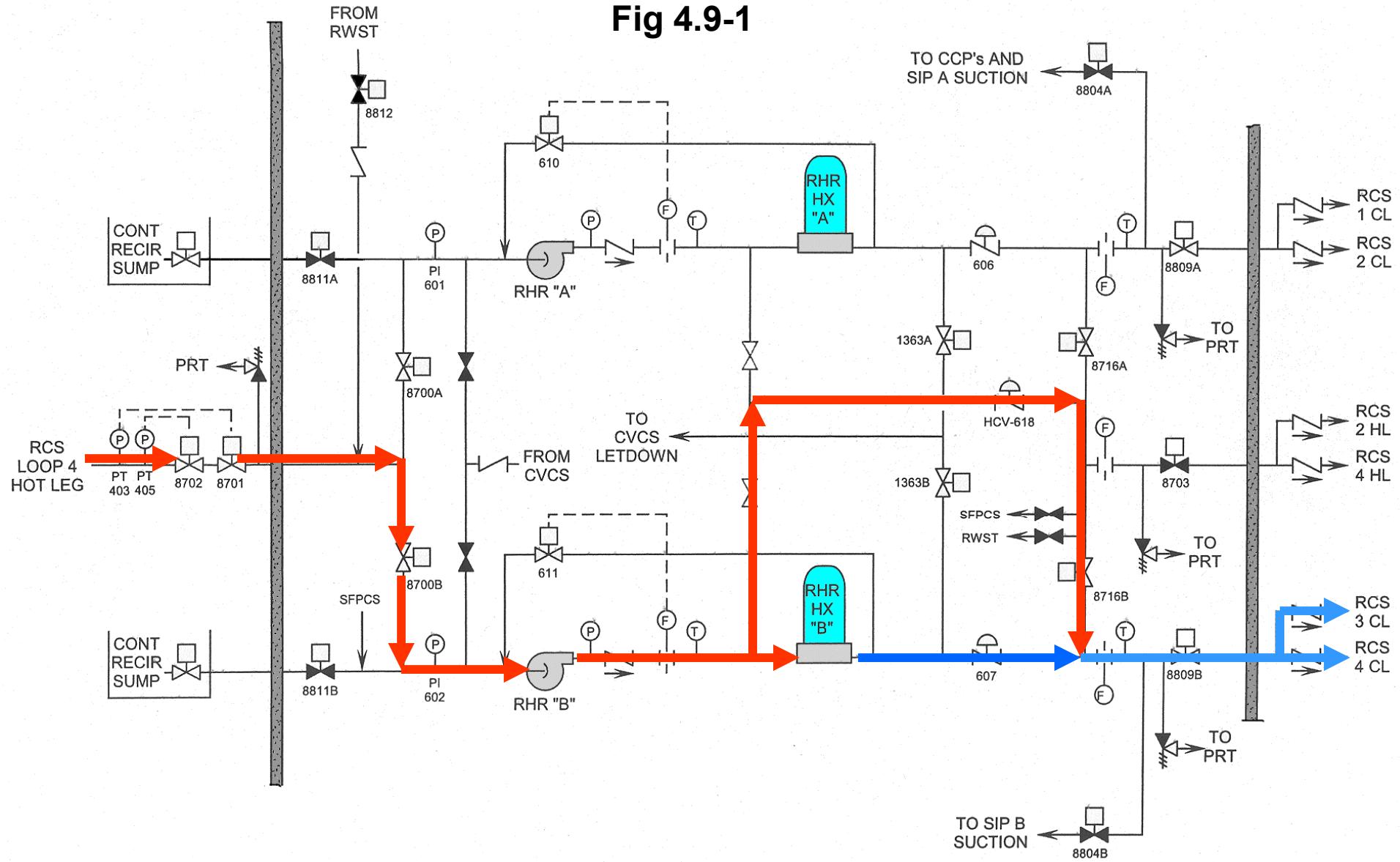
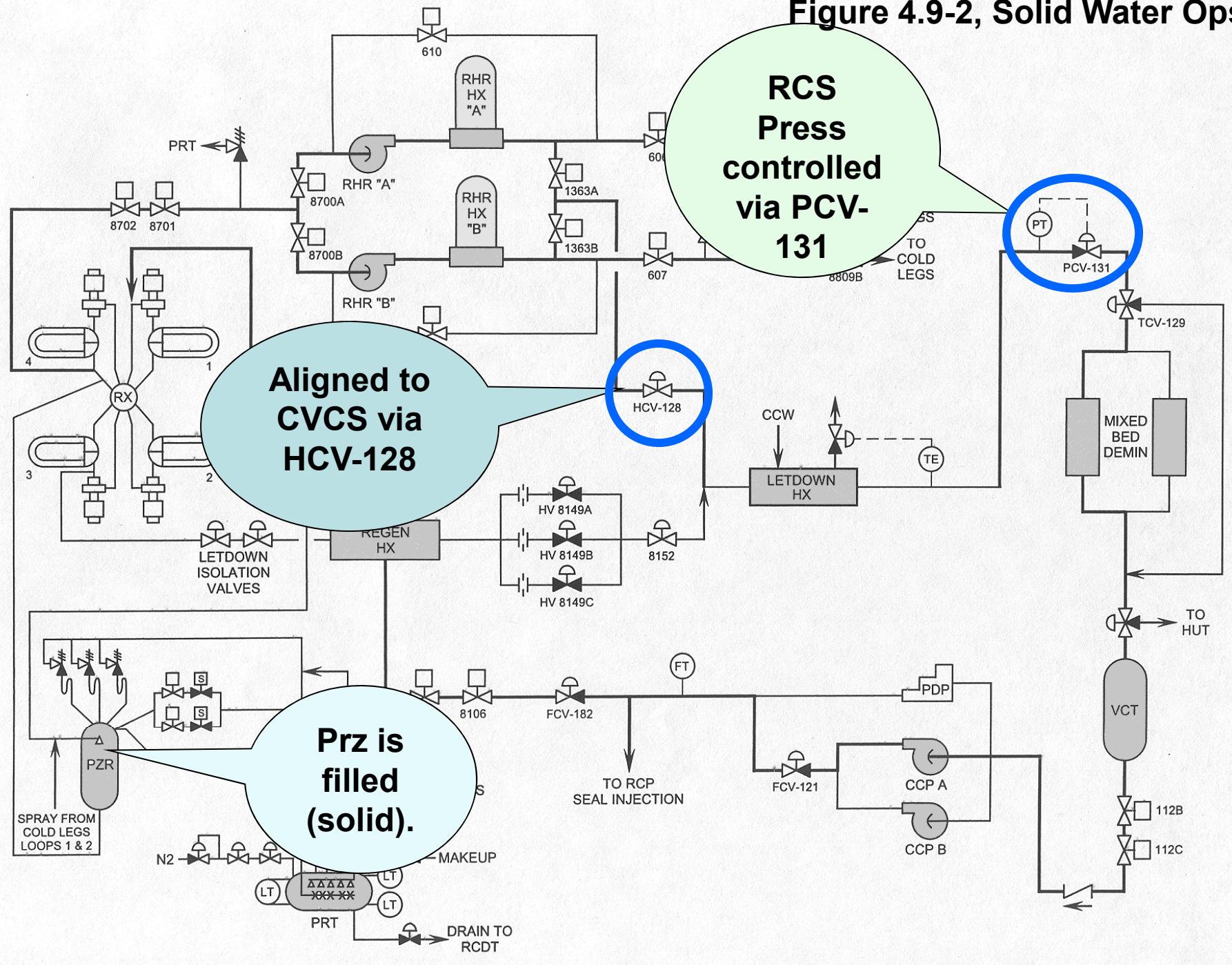


Fig 4.9-1



Shutdown Cooling Flow path (B Train)

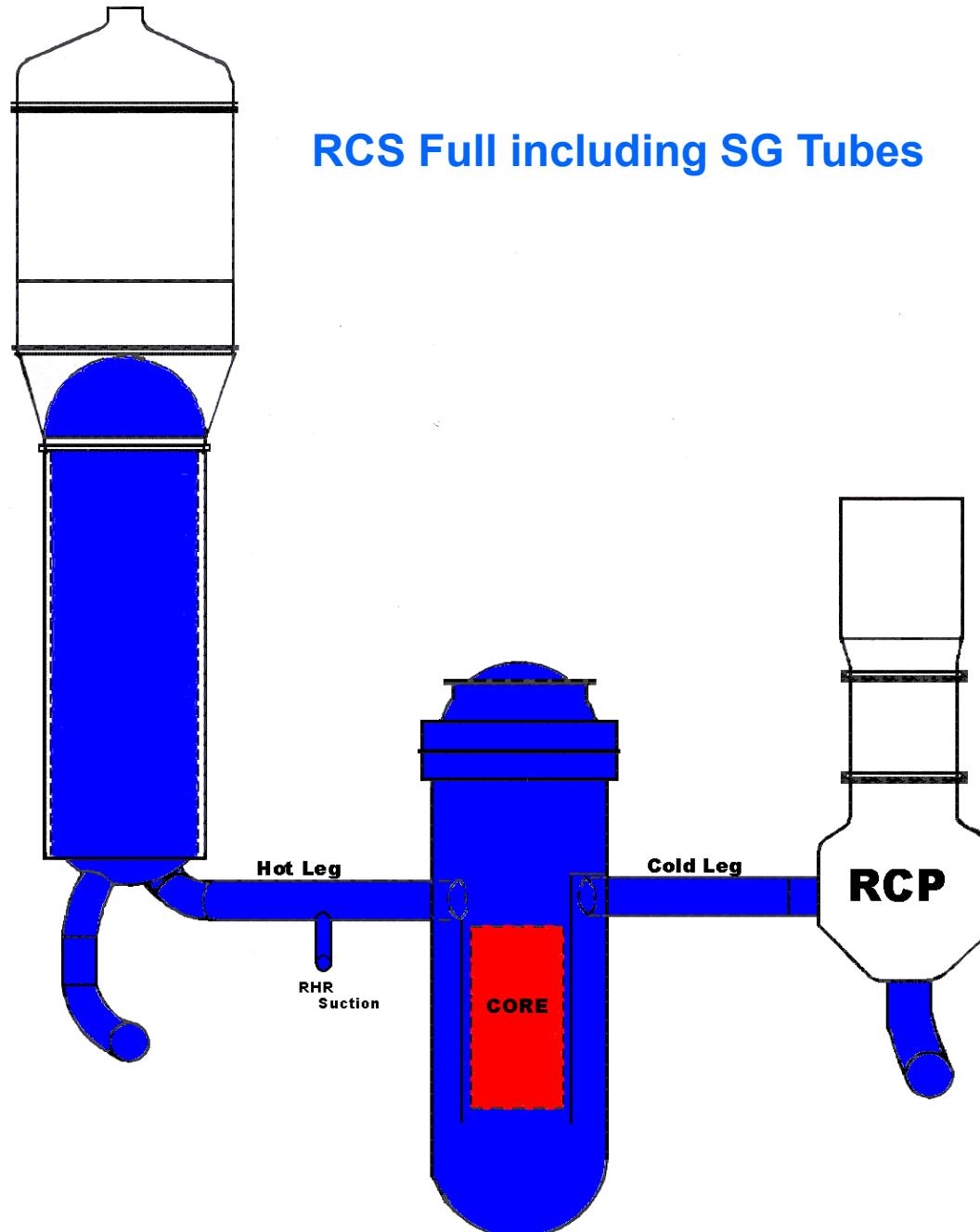
Figure 4.9-2, Solid Water Ops

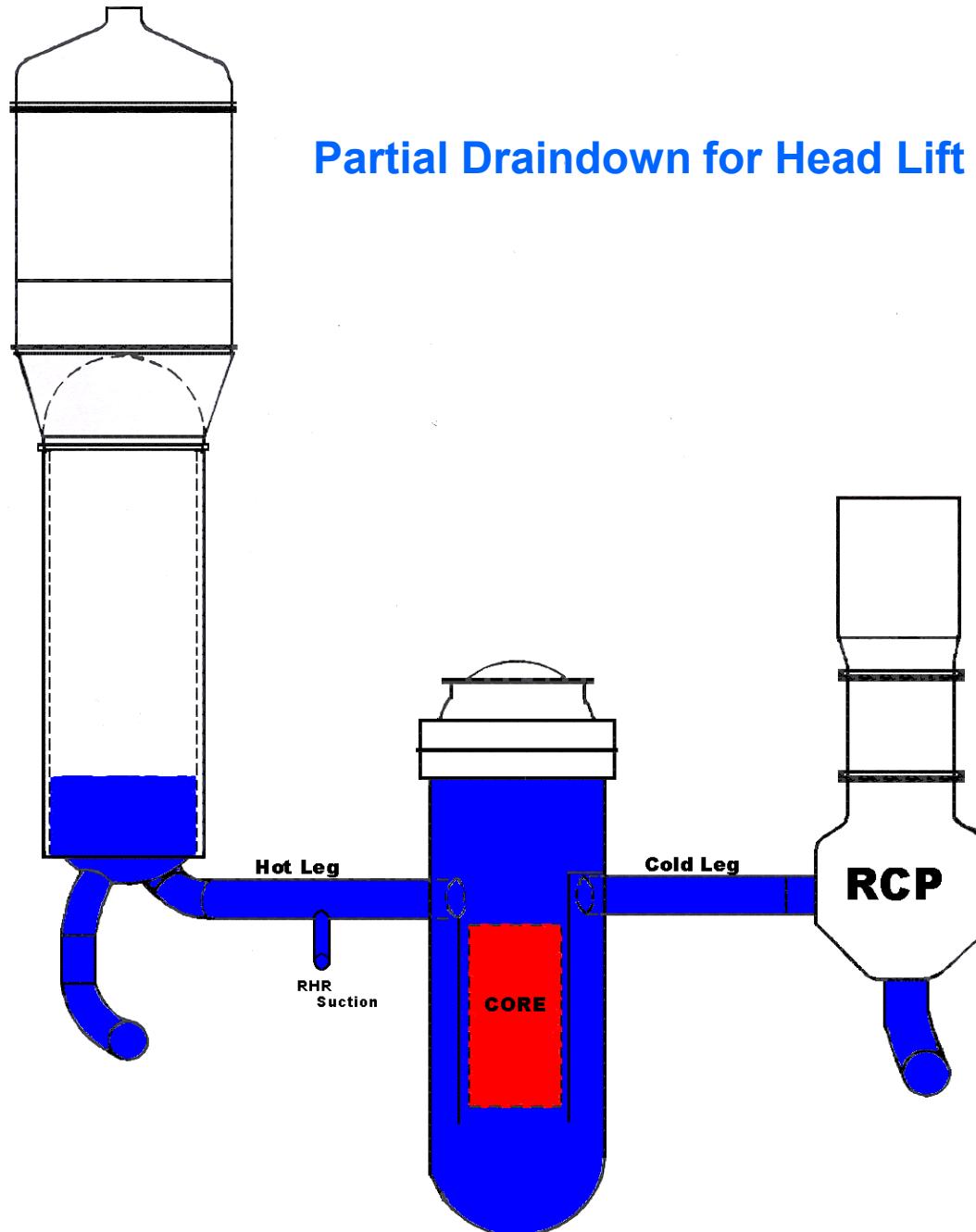


Design Features Effecting Reliability

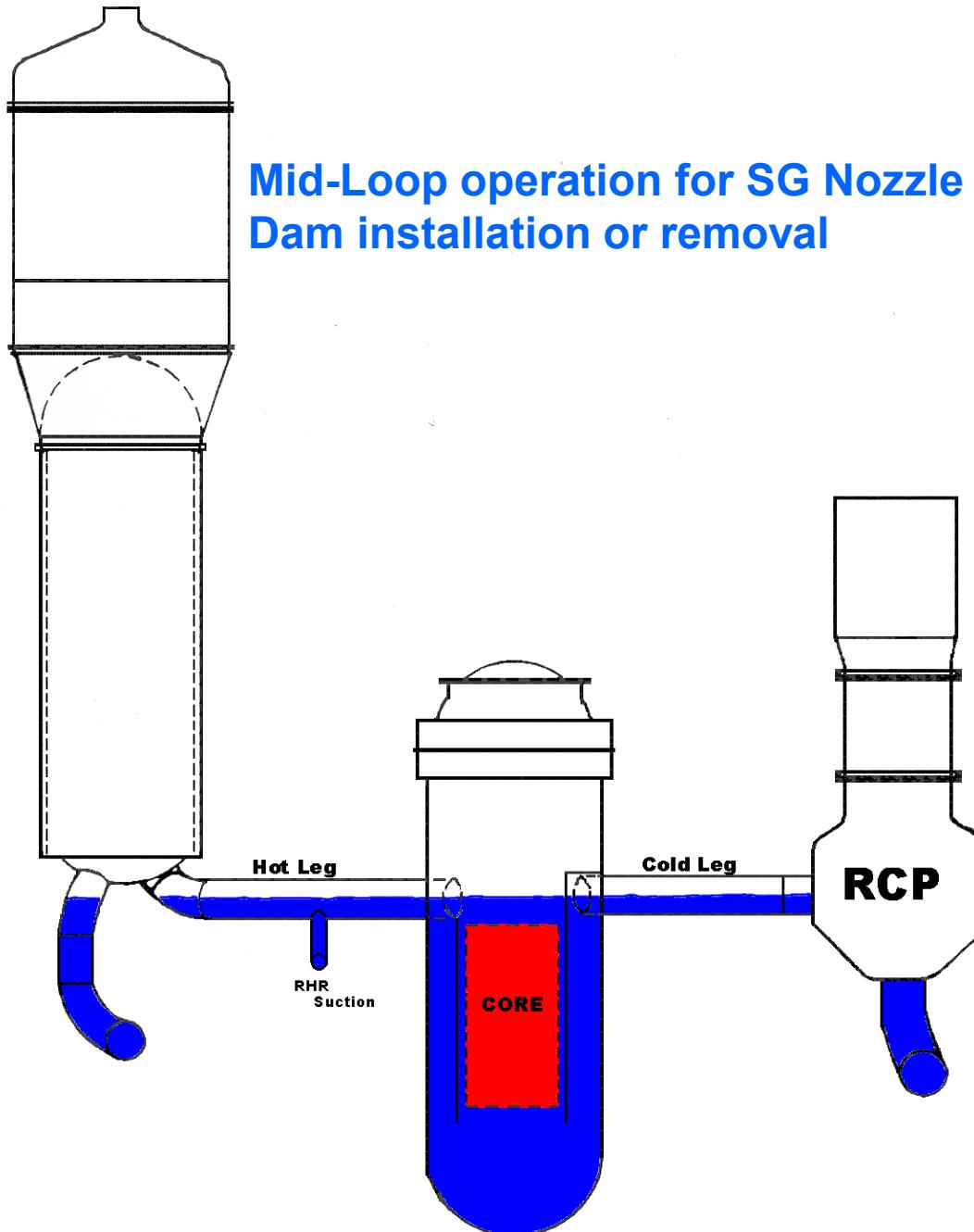
- Only one suction path from RCS hot leg. If one hot leg suction valve fails closed or is inadvertently closed, results in loss of decay heat removal.
- If an RCS overpressure event occurs, the RCS is automatically isolated from the relief valves in the RHR system. (this feature removed at most plants)
- RHR Piping Configuration. Potential for vortexing and air intrusion during reduced RCS inventory (i.e., mid-loop operations).







Partial Draindown for Head Lift



Consequences

Consequences of Losing Decay Heat Removal Capability in Cold Shutdown: Mode 5 ($K_{eff} < 0.99$ & $T_{ave} \leq 200$ deg. F).

- Fuel & cladding temperatures increase until clad oxidation and fuel melting begin.
- Possible uncontrolled release of radioactive fission products to the public once fuel degradation begins. (Containment integrity not required in Mode 5)

Plant Event Analysis

- National Safety Analysis Center (NSAC) analyzed 250 RHR related events at PWRs which occurred between 1977 and 82.
- About 100 of these events resulted in loss of or significant degradation of RHR while operating in the decay heat removal mode.
- These 100 events fell into three categories:
 1. Loss of RCS inventory via RHR System,
 2. Overpressurization of RCS, and
 3. Loss of long-term decay heat removal due to RHR system failures.

Plant Event Analysis

Some of the recommendations in the NSAC report include:

- Improvements in training and procedures related to loss of RCS inventory during RHR operation,
- Better administrative controls for maintenance & testing during cold shutdown, and
- Minor hardware mods including better control room indications and alarms for RHR flow, valve positions, valve controls, and reactor vessel water level.

Plant Events Analysis

- The NRC office for Analysis & Evaluation of Operational Data (AEOD) published “Decay Heat Removal Problems at US PWRs” in Dec 1985.
- Analysis indicated that the root cause of most events were related to procedural problems and personnel (human) errors.
- The leading cause of loss of decay heat removal was inadvertent closure of the suction isolation valves as a result of human error.
- One of the AEOD recommendations was to remove the auto close interlocks and/or power to suction valves to prevent inadvertent closure.

Important NRC Documents

There are numerous NRC documents related to shutdown cooling problems:

- RG 1.139, Guideline for RHR to Achieve and Maintain Cold Shutdown, 5/78
- GL 80-053, Generic Letter Concerning DHR Capability
- NRC Bulletin 1980-012, DHR System Operability
- USI A-45, Shutdown DHR Requirements, 3/81
- NUREG/CR-2799, Evaluation of Events Involving DHR Systems in Nuclear Power Plants, 7/82
- SECY 88-260, Shutdown DHR Requirements, 9/88
- GL 1988-017, Loss of Decay Heat Removal

Important NRC Documents

- NUREG-1289, Regulatory & Backfit Analysis: USI A-45, Shutdown DHR Requirements, 11/88
- NUREG/CR-5230, Shutdown DHR Analysis: Plant Case Studies & Special Issues, 4/89
- NUREG/CR-6832, Regulatory Effectiveness of USI A-45, 8/2003

Regulatory history

- 3/81: NRC designated “Shutdown DHR Requirements” as USI A-45 in NUREG-0705
- 9/88: SECY 88-260 “Shutdown DHR Requirements” was issued. Paper concluded that:
 1. Risks due to loss of DHR could be unduly high
For some plants,
 2. DHR vulnerabilities and CA's are strongly plant specific, and
 3. Detailed plant-specific analysis under the IPE program are needed to resolve issue.
- 11/88: NRC issued GL 88-20 which requested licensees to conduct IPE and consider DHR vulnerabilities as part of IPE.

Regulatory history

- 6/91: NRC issued GL 88-20, Supplement 4 which included a request to resolve the external event portion of USI A-45.
- 8/03: NUREG/CR-6832 was issued to access the effectiveness of GL 88-20 in reducing DHR related CDF. It concluded that:
 1. A significant reduction in DHR related risk was achieved as a result of generic requirements, and
 2. The alternate strategies for “feed & bleed” and “SG depressurization using condensate” helped lower the CDF’s. All plants took credit for at least one of these strategies.

Plant Events Examples

Diablo Canyon U-2 (4/1987)

- First refueling outage - S/D for last 7 days, RCS temp ~ 87°F, one train of RHR I/S at mid-loop to remove S/G access hatches (manways).
- LLRT testing I/P on RCP seal return line results in in-advertant draining of RCS through leaking valve.
- RHR pumps begin to cavitate when RCS level reaches point where vortexing occurs.
- RHR cooling lost for ~85 min. and boiling occurs in RCS. Steam exits vents in head resulting in personnel evacuation.
- Operators refill RCS from RWST and restore RHR.

Plant Events Examples

North Anna U-1 (6/1987)

- Loss of inventory due to RCP shaft leakage during RCP maintenance. Drawing a vacuum in the PZR masked the loss of inventory & non-condensable gases and vapor forming in Rx vessel head & S/G U-tubes.

Plant Events Examples

Braidwood U-1 (12/1989) IN 90-05

- S/D since 9/1989, plant solid at 350 psig & 175 deg., A-RHR I/S & B-RHR in S/B, one CCP in service, other CCP & both SI pumps tagged out for cold overpressure protection. Preps for drawing a bubble in PZR.
- A-RHR Suction RV lifted and would not reseat when RCS press ~ 411 psig (setpoint is 450).
- A-RHR had to be shutdown and isolated, B-RHR was placed I/S.
- RV was found to have foreign material in its internals.

Plant Events Examples

Braidwood U-2 (3/1990) IN 90-55

- Cold S/D preparing for refuel outage. B-RHR in service & A-RHR was in recirc mode to RWST.
- Operators preparing to shift from B-RHR to A-RHR.
- Operator inadvertently opened A-RHR suction valve.
- Flow path from RCS to RWST. Immediately recognized error.
- Suction valve stroked open and then stoke closed.
- ~ 9500 gal from RCS to RWST. PZR exceeded C/D rate.

Plant Events Examples

Watts Bar Unit 1 (9/10/03)

- Plant performing blackout EDG testing, B Train RHR I/S, C-S CCW Pump I/S supplying B Train CCW to RHR Hx.
- Due to a procedure problem C-S CCW Pump is left aligned to A Train power. Operators initiate A Train blackout test which strips the C-S Pump off the A Train 6.9 KV Sd brd.
- Takes 12 minutes to restore B Train CCW, RCS heats up ~ 15°F.

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